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Asteroid capture using lunar flyby

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Abstract

This paper focuses on the approach which enables us to capture an asteroid using the lunar flyby. Assume that the asteroid is able to enter the Earth–Moon system. The orbits of the asteroid before and after lunar flybys are investigated for different Jacobi constants in the restricted three body problem. The capture will happen when the post-flyby Jacobi constant reaches certain value due to the flyby. The capture regions of different pre-flyby initial Jacobi constants are numerically explored in the diagram that is represented by two defined angles. To give an intuitive description of the capture region, it is represented by the orbital elements of the asteroid. Based on this capture region, the asteroids that can be captured through lunar flybys are chosen from the asteroid database. Finally, the capture processes of selected asteroids are validated through the ephemerides model.

Keywords: Near earth asteroid; Capture; Restricted three body problem

1. Introduction

Asteroid capture can happen, either naturally or artificially, when an asteroid approaches a large planetary body and remains temporary or permanently captured by it. Natural satellite capture by a planet has always been a popular topic in celestial mechanics as a way of explaining the origin of various satellites of the system, noteably the Jupiter's moon (Nesvorny et al., 2007 and Philpotta et al., 2010), and the Neptune's moon (Agnor and Hamilton, 2006). Typically asteroids are thrown out into space or impact the body when they approach the planet. In rare instances, the asteroid is captured in an orbit around the planet. This capture is possible given the right conditions in the framework of the restricted three body problem with the Sun and the planet as primaries. It has been proven that it is impossible to capture an asteroid permanently with a purely gravitational mechanism because almost every particle will pass arbitrarily close to its initial position in phase space (Tanikawa, 1983). As a consequence, some non-gravitational scenarios of capture such as gas drag mechanism have been proposed to facilitate permanent capture (Pollack et al., 1979). All the hypotheses require a temporary gravitational capture by the planet as the first stage. Topputo and Belbruno (2009) defined the weakly stable boundary to describe the temporary capture, which are trajectories that begin out of the Hill region of the restricted three body problem and enter the region to orbit the planetary satellite at least one time. The capture dynamics and chaotic motion in the restricted three body problem was thoroughly studied by Belbruno (2005). There are also works about numerical simulations to seek temporarily captured objects (Cline, 1979; Paskowitz and Scheeres, 2006).

Besides exploring the mechanism of nature satellites capture, many literatures also focused on the idea to exploit the natural resources of asteroids (Hasnain et al., 2012; Mazanek et al., 2013). This idea is older than the

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space program and gains attention again as the technology makes it possible to capture an asteroid artificially. To test the validity of this assertion, NASA sponsored a study in 2010 to investigate the feasibility of capturing a small near-Earth asteroid (NEA) to the International Space Station (ISS) by 2025 (Brophy et al., 2011). On June 19, 2014, NASA reported that asteroid 2011 MD was a prime candidate for capture by the Asteroid Redirect Mission (ARM), perhaps in the early 2020s (Borenstein, 2014). There are several motivations of capturing a NEA. The main reason is to gain convenient access to its resources. In addition, the captured asteroid may be used against an incoming, threatening body (Massonnet and Meyssignac, 2006) and contribute to missions aimed at exploring solar system (McAndrews et al., 2003).

There are several challenges to capture an asteroid, including target identification and target capture. Hasnain et al. (2012) studied the acceleration requirement to transport different asteroids to the sphere of influence (SOI) of the earth, along with the impulse or acceleration necessary to capture the asteroid into a bound orbit at the SOI. Cline (1979) studied a different type of capture scenario, in which an existing natural satellite of a planet is used to capture a third body into a closed orbit about the planet. This method can lower the propellant requirements for putting spacecraft in orbits around other planets. Galileo mission to Jupiter includes a flyby of the moon Io near the orbiter's arrival perijove (D'Amario et al., 1992). Cassini also conducted a close flyby of Phoebe before its Saturn Orbit Insertion maneuver (Peralta and Flanagan, 1995). The main purpose of these flybys is to use the moon's gravity to lessen the velocity decrement needed for orbit insertion. Therefore, it is natural to think of utilizing the moon of earth to lower the velocity of an approaching asteroid to achieve a natural capture. However, the asteroid capture is different from the spacecraft capture in that the trajectory of an asteroid cannot be designed. It is only possible for the asteroids that approach the Earth–Moon system and a small orbit modification is applied to make the flyby happen. The asteroid deflection has been widely studied for the purpose of planetary defense (Hills, 1992; Lu and Love, 2005). The question remains to be answered is what kind of asteroids will be captured after the lunar flyby.

In this paper, a two-step process is proposed to find the asteroids that will be captured after lunar flyby. Firstly, this capture is studied in the restricted three body problem and the flyby is represented by patched conic two body analysis. The capture region is plotted in a two-dimensional space spanned by the direction angle of the approaching velocity of the asteroid and the angle determining the flyby position. The pre-capture heliocentric orbital elements of the asteroid in the capture region are constructed to provide a reference to select target asteroid. Secondly, the full ephemerides model is used to design the capture trajectory.

2. Mathematical model and algorithm

2.1. Planar restricted three body problem

The model is the planar circular restricted three-body problem (RTBP). This problem defines the motion of an asteroid in a gravitational field generated by the mutual circular motion of the sun and earth of masses m_1 and m_2, respectively, about their common center of mass. It is assumed that the moon moves in a circular orbit around the earth in the plane of motion of the sun and earth. The moon and the asteroid do not influence the motion of the sun and earth. A rotating coordinate system, $oxyz$, is defined. Its origin is at the center of mass of the sun and earth and the x-axis passes through them. This is a barycentric rotating coordinate system (see Fig. 1). The coordinate can be chosen in dimensionless units, with the angular frequency of the circular motion of the sun and earth normalized to one, and the distance between them also normalized to 1. The sun is located at $(-\mu, 0)$ and the earth is placed at $(1-\mu, 0)$, where $\mu = m_2/(m_1 + m_2)$. The dimensionless mass of the Sun and Earth are $1-\mu$ and μ, respectively.

The equations of the motion of the asteroid can be written as (Szebehely, 1967)

$$\begin{cases} \ddot{x} - 2\dot{y} = \Omega_x \\ \ddot{y} + 2\dot{x} = \Omega_y \end{cases} \tag{1}$$

where

$$\Omega = \frac{1}{2}\left(x^2 + y^2\right) + \frac{1-\mu}{r_1} + \frac{\mu}{r_2}$$

where r_1 and r_2 are the distances from the sun and earth, respectively.

$$r_1 + \sqrt{(x+\mu)^2 + y^2}, \; r_2 = \sqrt{(x+\mu-1)^2 + y^2}$$

Eq. (1) admits an integral of motion, the Jacobi energy,

$$C = 2\Omega - v^2 \tag{2}$$

where

$$v^2 = \dot{x}^2 + \dot{y}^2$$

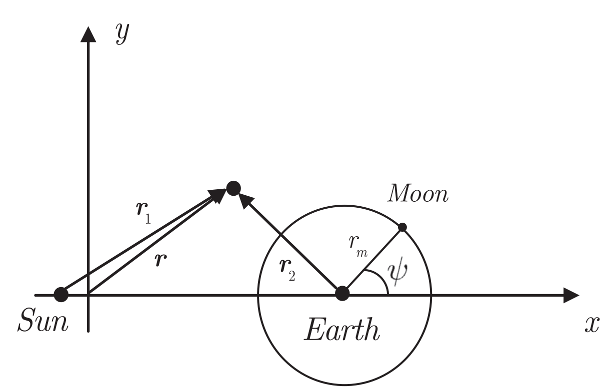

Fig. 1. Planar Sun-Earth restricted three body problem.